Design and Construction of a Pesticide Spraying Machine for Chili Plants on Ridge fields

Wisnaningsih[1*], Muhammad Iqbal Maulana[2], Wawan Hermawan[2]

[1] Department of Mechanical Engineering, Saburai University, Lampung, Indonesia.
[2] Department of Mechanical and Biosystem Engineering, IPB University, Bogor, Indonesia.
Email*): wisnaningsih1968@gmail.com

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Abstract: Pest and disease attacks on chili plants are typically handled by pesticide spraying using backpack sprayers, which pose health risks to operators due to pesticide exposure and the weight of the equipment. The proposed solution is the development of a remote-controlled pesticide sprayer designed for ridged fields. This machine is equipped with a frame, track-type wheels, a drive motor, a water tank, a water pump, and navigation using a First Person View (FPV) camera. The machine is controlled via a remote control with a range of up to 200 meters. Performance testing shows that the machine moves at an average speed of 0.30 m/s, with an average track wheel slip value of 8.32% and a maximum slip of 10.65% when carrying a full water tank. The machine is equipped with 4 nozzles positioned as needed, with an average flow rate of 0.87 L/minute. The average current required for the driver motor is 9.1 A, while the current for the pump remains stable at 2.14 A. The control system consists of a cytron motor driver for the drive motor and a relay for controlling the on/off function of the water pump.

Keywords: machine sprayer; remote control; tracked wheels

INTRODUCTION

Background

Chilies are among the food items with highly volatile prices. For many Indonesians, chili is an essential spice that is always present in daily cooking. A significant increase in chili prices can affect people's purchasing power and trigger concerns (Nauli, 2016). In 2015, the national average red chili consumption reached approximately 1.070 million tons per year, with prices ranging from IDR 30,000 to IDR 40,000 (Ministry of Agriculture, 2018). This data indicates a high demand for chilies in Indonesia. However, the Central Bureau of Statistics (BPS, 2016) reported a decline in chili production from 1,003,481 tons in 2014 to 937,925 tons in 2015. The decline was mainly caused by crop failures due to drought and pest infestations in chili-producing regions in Java. One of the major threats to chili production is anthracnose disease, which can cause yield losses ranging from 20% to 100% (Diao et al., 2017). Anthracnose is caused by the fungi Colletotrichum capsici and Gloeosporium piperatum (Oo & Oh, 2016; Syukur et al., 2014).

In addition to diseases, chili plants are also frequently attacked by pests such as the green peach aphid (Myzus persicae Sulz). The symptoms of aphid infestation include the sucking of sap from young leaves, resulting in yellow spots on the affected foliage (Amalina et al., 2018). To control pests and diseases, farmers commonly use synthetic pesticides both before and after harvest. However, excessive pesticide use poses potential health risks. Traditional pesticide spraying methods, such as backpack sprayers, have several limitations, particularly in terms of efficiency and farmer safety. Farmers using backpack sprayers often experience fatigue and exposure to pesticide residues, which can negatively impact their health. According to Meliana et al. (2024), agricultural spraying frequently causes pain in the shoulders, neck, lower back, and legs due to carrying a 20-50 kg load during application. The use of motorized sprayers, which weigh around 10.6 kg when empty, also presents challenges, as operators report discomfort from the weight, strong liquid movement inside the tank, and excessive motor vibrations (Hermawan, 2014). Additionally, conventional spraying methods expose operators to inhalation risks from pesticide residues (Maksuk et al., 2018; Silva-Barni et al., 2019; Zhou et al., 2019). Pesticides themselves are classified as toxic or highly toxic substances when misused (Damalas & Koutroubas, 2016; Carvalho, 2017). Based on interviews with a farmer in Pamijahan Subdistrict, Bogor Regency, chili spraying is conducted once or twice per week during the dry season and at least twice per week in the rainy season, especially after rainfall to prevent moisture-related diseases. Pesticides are applied every 5 to 7 days to protect crops (Diem & Giao, 2022). In chili farming areas in Central Java, farmers spray approximately 23 times per planting season, which lasts three to four months (Mariyono, 2017).

The implementation of technological innovations in agriculture can improve cultivation efficiency while reducing the risk of injury to farmers. These innovations can be applied throughout the farming process, from seedling to harvesting and pesticide spraying (Colantoni et al., 2018). Various navigation methods are utilized in agricultural machines, including Global Positioning System (GPS), point-cloud localization, line following, and remote control. The integration of robotics and mechatronics into pesticide spraying enables contactless operation, enhancing worker safety (Poudel et al., 2017). Several pesticide spraying machines for horticultural crops have been developed, such as the design by Fahri (2019), which sprays pesticides through nozzles on both sides of the machine and is operated via an HC-05 Bluetooth remote control. This machine can dispense 5 liters of pesticide in 6 minutes. However, its control range is limited to 15 meters in an open area and only 5 meters when obstacles are present. Another pesticide spraying machine was developed by Budiono (2021), utilizing a wall-following system based on ultrasonic sensor readings to navigate raised beds in conventional agricultural fields. This machine automatically detects chili plants at a maximum distance of 90 cm and sprays them efficiently without excessive pesticide use. It moves at a speed of 0.312 m/s, with a spray height of 60 cm, a spray width of 115 cm, and a discharge rate of 17.94 ml/sec. However, the machine has limitations in performing U-turn maneuvers, requiring a wide turning space in the field.

Given these challenges, there is a need for a solution that facilitates the spraying process, particularly in raised-bed farming systems. Unlike drone-based spraying, chili cultivation requires pesticide application beneath the leaves to maximize coverage in areas where pests typically reside. This research aims to design a pesticide spraying machine capable of operating in raised-bed farms while efficiently targeting pest-prone areas. Additionally, this study seeks to improve farmer safety by reducing pesticide exposure through remote spraying technology. Furthermore, this study aims to enhance the performance of previous designs, particularly by improving the U-turn maneuvering mechanism, allowing for more efficient operation in limited field spaces.

Aims

This research aims to design an unmanned pesticide spraying machine that can move on the furrow and spray pesticides effectively at points that are usually a hotbed of pests and diseases in chili plants. This machine is designed to be remotely controlled and function properly. In addition, this research also aims to improve farmers' health by reducing pesticide exposure through unmanned spraying technology.

MATERIALS AND METHODS

Study Site and Data Collection

The research process was conducted from May to September 2024 and was divided into two stages, namely the design and manufacturing stage, and the testing stage. The design and manufacturing stages were carried out at the Siswadhi Soepardjo Laboratory, Department of Mechanical Engineering and Biosystems, Faculty of Agricultural Technology, IPB University. While the testing phase was carried out in the chili cultivation field located at Jalan Gunung Bunder I, Pamijahan District, Bogor Regency, West Java.

Identification of Problems and Design Criteria

The problem identification process begins with the collection of initial data regarding spraying activities on chili plants, such as the characteristics of the ridge fields used in chili cultivation, the forward speed of spraying, and the characteristics of chili plants. According to Putri et al., (2023), the height of curly red chili (*Capsicum annuum* L.) plants can reach 90-100 cm, which is an important factor to consider. Additionally, the ridge fields in chili cultivation typically measure 1 meter in width with a spacing of 50 cm between ridges. The ridges are 30 cm high, and the trenches separating them are 50 cm wide and 30 cm deep, ensuring adequate drainage and separation between planting areas (Antriyandarti et al., 2023; Harahap et al., 2021). The ridges are accompanied by trenches around 30 cm deep in dryland farming, while in paddy fields, the furrow between ridges is typically 50 cm deep to support drainage. This data becomes the basis for designing the structural and functional aspects of the machine, such as spray range and machine mobility between ridges. By identifying this problem, the limitations that need to be considered in the design of the machine can be determined, so that the resulting tool is able to operate optimally in the conditions of the ridges that can be seen in Figure 1.

Figure 1. Land condition of chili cultivation in Pamijahan Sub-district

Based on the data from the problem identification results, some of the design criteria for the pesticide spraying machine design for chili plants are expected, namely:

1) The machine can run optimally on the path between ridges while carrying a machine load of 45 kg.

2) The machine can drive at a speed of 0.25-0.30 m/s while spraying both the right and left sides simultaneously.
3) The machine can perform U-turn maneuvers and executing movement mechanisms optimally when entering the next ridge row.
4) The machine can spray pesticides on chili plants up to a height of 100 cm, targeting both the top of the plant and the underside of the leaves.
5) The pesticide tank is detachable to facilitate refilling by farmers.
6) The sprayer machine can be controlled remotely within a 50-meter radius.

General Concept

The general design of this machine utilizes a DC motor as its drive system, with rotational speed adjusted according to operational needs. The machine is designed to move along the trench between two raised beds, allowing it to effectively spray plants on both sides simultaneously. The selection of the water pump is based on the typical flow rate used in backpack sprayers, which is 3 L/min for spraying a single row of plants. In this machine design, nozzles are placed on both the right and left sides, enabling the spraying of two rows of plants at once. Therefore, a pump with a flow rate of 6 L/min is used to ensure optimal spray coverage. The machine is designed to efficiently perform a U-turn maneuver, with an independently controlled motor system for better maneuverability. The drive wheels use a track system consisting of gears and chains that are readily available on the market. The use of track wheels is intended to maximize traction when operating in agricultural fields. Additionally, the machine is equipped with a First Person View (FPV) camera to assist users in navigation when controlling the machine remotely. The general design concept can be seen in Figure 2.

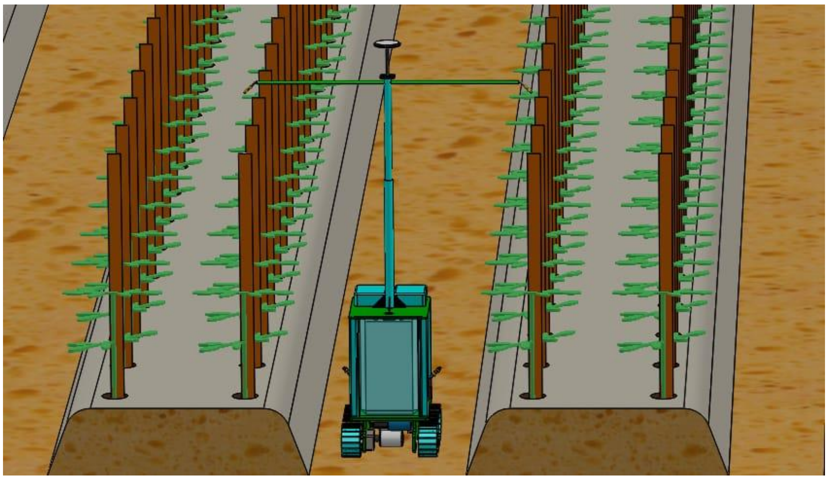

Figure 2. Pesticide sprayer machine design for raised bed fields

Functional Design Analysis

The functional design analysis describes the main functions of the tool applied to each component. Based on these main functions, the functional design is described in Table 1. The results of this functional design analysis are used to select the appropriate components as the tool structure and the mechanism chosen as a benchmark for the success of the tool design.

Table 1. Functional design of the machine

No.	Functional Design	Component	Structural Design
1.	Power Source for Machine Movement	DC Motor	12V DC motor with 90 RPM

2.	Machine Traction Provider for The Field	Track Wheels	Uses a 12 cm diameter chain and gear, supplemented with an A-type V-belt segment
3.	Power Source	Battery (accumulator)	Battery with a capacity of 50 AH and 12V voltage
4.	Water reservoir	Water Jerry Can	Water tank with a capacity of 18 liters
5.	Water pumping mechanism	DC Pump	12V DC pump with a flow rate 6 liters per minute
6.	Water distribution mechanism	Hose	Uses a hose with an outer diameter of 10 mm and an inner of 6 mm, with pneumatic type connectors
7.	Integration and Support of All Components	Iron Frame	The main frame is made of 3 mm iron plate and 2.5x2.5 mm angle iron
8.	Machine Movement and Pump Output Control	*Cytron Motor Driver,* Relay, and Flysky Remote Control	Cytron motor driver control forward, backward, and turning movements of the DC motor, the relay regulates input current to the DC pump, and the Flysky remote controls both
9.	Navigation Assistance	FPV Camera	Display the machine's path conditions on the field

Structural Design Analysis

Structural design analysis plans the component structure to fit the size and design criteria needed for the spraying machine to work optimally. The structure of this pesticide spraying machine consists of a frame, track wheels, motor, battery, pump, and nozzle.

The frame is the important component of this pesticide spraying machine. It plays a crucial role in ensuring that the components are positioned optimally. The frame is designed in such a way that the machine can operate according to the planned technical requirements and limitations. The material used for constructing the main frame is 2.5 x 2.5 cm black angle bar and 3 mm thick iron plate. Angle bar was chosen due to its sturdiness while being relatively lightweight. Additionally, the choice of angle bar is tailored to the component layout needs, allowing for minimal material use. The strength analysis of the main frame was conducted using the Solidworks 2023 application with a load of 40 kg distributed across the surface of the main frame made from JIS G4051 grade S30C steel. According to Mustafid (2022), this type of steel has a tensile strength of 490 MPa, a yield strength of 294 MPa, and a density of 7.85 g/cm^3. The stress and displacement testing results can be seen in Figures 3 and 4.

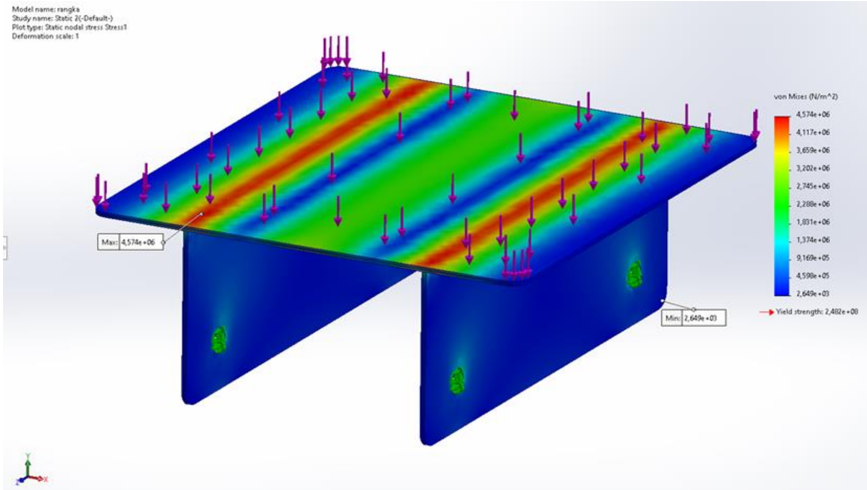

Figure 3. Frame stress analysis in solidwork 2023

Figure 3 shows the results of the stress analysis simulation (von Mises) on the structural frame using the Finite Element Analysis (FEA) method. The frame, consisting of plates and beams, is depicted with purple arrows indicating the direction and location of the 40 kg compressive load applied evenly across the frame's surface. The von Mises stress is displayed on a colour scale, where blue represents areas of low stress and red represents areas of high stress, nearing the material's yield strength, marked at 2.482×10^8 N/m^2 (red line). The results of this analysis indicate that, under a 40 kg load, the frame experiences a stress distribution that remains below the yield strength limit, suggesting that the structure can optimally bear the load without undergoing permanent deformation.

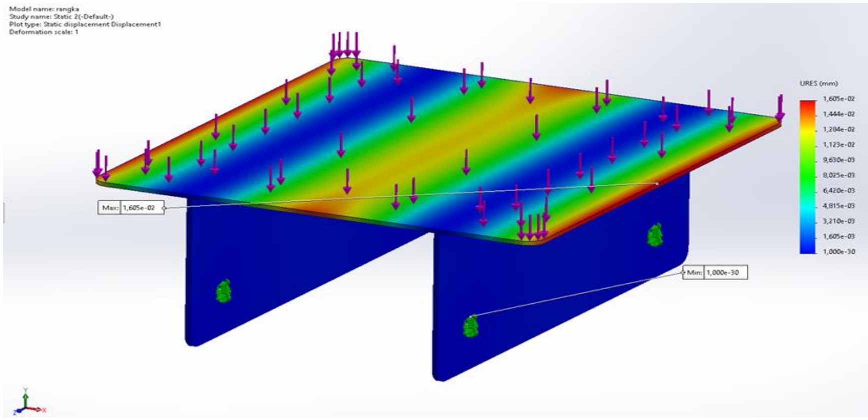

Figure 4. Frame displacement analysis in solidwork 2023

Figure 4 shows the results of the displacement analysis (URES) in millimetres, with red indicating the maximum displacement of approximately 1.605 mm and blue indicating the minimum displacement, approaching zero. The applied load is represented by purple arrows on the structure, resulting in a displacement distribution where the upper edges of the frame show more significant displacement compared to other parts. Although there is minor deformation, the low displacement scale indicates that the frame is sufficiently rigid and capable of bearing the load well without significant displacement. Both analysis results show that the material used for the main frame, a 3 mm thick plate made of JIS G4051 grade S30C steel, is adequate to support a 40 kg load.

The track wheels are used on the machine to provide traction from the driver motor. The purpose of using track wheels is to minimise slippage during machine operation on the field. The track wheel assembly consists of several components: sprocket, flanged chain, bearing block, axle, and traction pads. The sprocket functions as the transmitter of rotational power from the motor, which then moves the machine. The sprocket used is a type of RS-40 with 24 teeth and a diameter of 12 cm, which approximates the required target wheel diameter. The chain is used to transfer rotational power from the sprocket to the traction pads, which will contact the ground or field. The chain used is an RS-40 type with additional flanges on both sides of each link. Bearing blocks are used to support the axle of the wheels, allowing it to rotate around the predetermined axis. Six bearing blocks are used, type KFL 103. The axle used in this track wheel assembly has a diameter of 13 mm, matching the motor output and the sprocket bore diameter. The traction pads are made from cut-up sections of used V-belt, each 6 cm in length. The wheels are designed with a width of 6 cm on each side, providing more stability compared to regular wheels (Figure 5).

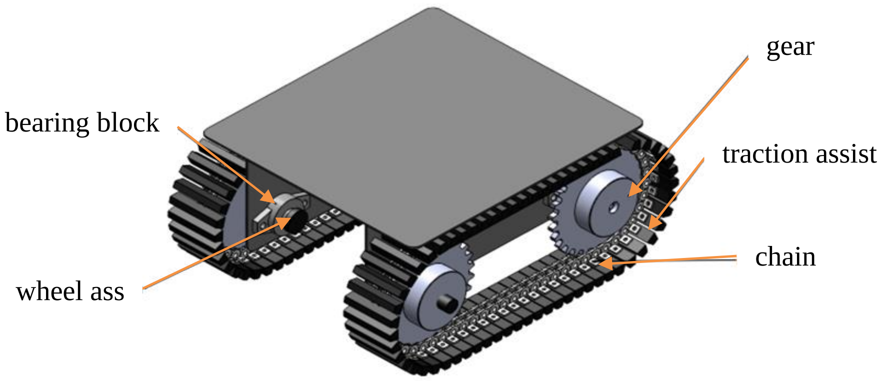

Figure 5. Track wheel components

The motor as the main power source for this machine, generates rotational force to move the track wheels. This rotational force is reduced by a gearbox to achieve a rotational speed that meets the design criteria. The motor selected has sufficient power to move all components, including the frame, battery, and water jerry can. The parameters that influence the motor's power requirements include the total weight of the machine and rolling resistance. The weight of the components was measured manually using a digital scale. The weight of the components includes the battery at 15 kg, the frame and track wheels at 12 kg, and the full jerry can at 18 kg. The machine's average rolling resistance with varying water tank capacities, from 0% to 100%, is 9.25 kg. A 12V DC motor with 90 RPM was chosen to drive the machine's wheels, with a total weight of 45 kg and a rolling resistance of 9.25 kg. The wheel torque was calculated by multiplying the rolling resistance by the wheel radius of 0.07 m, resulting in a torque of 6.35 Nm. The wheel's angular velocity is calculated from the rotational speed of 90 RPM using the formula:

$$\omega = \frac{(2\pi \times \text{Wheel Spin Speed})}{60} \quad (1)$$

This gives:

$\omega = (2\pi \times 90) / 60 = 9{,}42$ rad/s

Next, the rotational power of the wheel is calculated using the formula:

$$P = \omega \times T \quad (2)$$

resulting in a power of 59.82 Watts. With an electric motor efficiency of 75%, the motor power required is calculated by dividing the rotational power by the previously calculated torque, yielding a power of 79.76 Watts. The selected motor must have a power rating greater than 79.76 Watts and a current of 6.7 A.

The battery functions as the main power source for operating the motor and pump on this pesticide spraying machine. The selection of the battery is based on the power requirements of the motor and pump, ensuring the machine can operate optimally for the planned duration. The battery used is a lead-acid type (wet cell) capable of providing sufficient power to drive the entire system over an area of 0.25 hectares. The battery capacity is determined to meet the machine's power needs while traveling at a speed of 0.25 m/s. The field planting pattern consists of rows arranged in an area 25 m wide and 100 m long, with a width of 120 cm and a spacing of 50 cm between ridges, as shown in Figure 6.

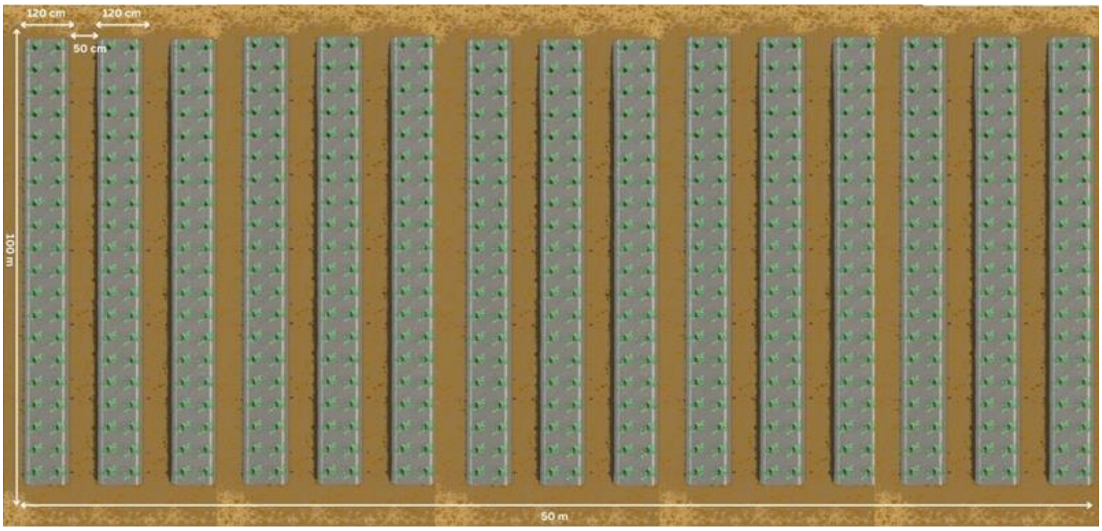

Figure 6. Path pattern in the chili cultivation ridge field

Based on the planting pattern, the machine will travel a path of 1,618 metres on the field, resulting in an estimated travel time of 1.80 hours. The determination of battery capacity is based on the total power requirement from the energy consumption of a 12V water pump and two 12V DC motors. The power requirement for the water pump (E1) is determined by testing the current usage with four nozzles, resulting in a measured current of 2.14 amperes. According to Susanti et al. (2019), battery capacity can be calculated using the following formula:

$$E1\ (Ah) = \frac{I \times t}{\text{efficiency}} \quad (3)$$

Then,

$$E1\ (Ah) = \frac{2.14 \times 1.8}{80\%} = 4.82\ \text{Ah}$$

The required battery capacity of the drive motors (E2) is calculated using the following formula:

$$E2\ (Ah) = \frac{I \times t}{\text{efficiency}} \times \text{n} \quad (4)$$

where:

E2 = Battery capacity (Ah)
I = Current (ampere)
n = 2 (number of motors)
efficiency = 80%

The ampere current in the motor is determined by testing the machine with the weight of the frame and jerry cans that are fully loaded without loading the battery weight. Experimental data obtained is 8.5 amperes, then:

$$E2\ (Ah) = \frac{8.5 \times 1.8}{80\%} \times\ 2 = 35.55\ \text{Ah}$$

The battery capacity requirement was further calculated based on the increased current when adding the battery's weight. The average battery weight for a 35-45 Ah capacity battery is assumed to be 10 kg. Another current measurement was taken with the machine loaded with the frame, fully filled jerry can, and battery. The current measurement for the machine moving forward was 9.85 A, so the power requirement for the motor under load is:

$$E3(Ah) = 9.85 \times\ 1.57\ \times 80\% = 44.33\ Ah\ **$$

Thus, the total battery capacity required is the sum of the power needed for both the pump and motors. The total battery capacity needed is 49.14 Ah. A 50 Ah battery was selected based on availability and proximity to the required capacity in the market.

The pump is the main component responsible for spraying pesticide from the jerry can to the nozzles. The pump used is a 12V DC pump with a flow rate of 6 l/minute debit. The pump capacity is adjusted based on the capacity used in backpack sprayers, but with a flow rate twice as high due to the four nozzles installed. The pump is operated automatically, powered by the battery, and controlled directly through a controller connected to a relay to manage the pump's on/off function.

The nozzle functions to adjust the pesticide spray pattern to the plant evenly and according to the spraying needs. On this machine, there are 4 nozzles, with the placement of 2 nozzles on the right side and 2 nozzles on the left side. The use of pneumatic connectors on the pump outlet connection allows the selection of the number of nozzles used more easily. the nozzle used is a flat fan nozzle type that can produce spray with a wide and even range. The flat fan type nozzle has an effective spraying width of 122 cm (Sari & Prasetio, 2021). Meanwhile, according to Kagurnita & Pramuhadi (2024) the flat fan type nozzle has an effective spraying width of 136 cm and a spray angle of 100º. In addition, the droplet diameter output produced in the use of liquid organic fertiliser using a flat fan type nozzle is 195.44 μm. So that the use of a flat fan type nozzle can maximise the nozzle spray coverage area. According to Riani et al. (2024), pictures and specifications of flat fan type nozzle can be seen in Figure 7 and Table 2. The number of nozzles installed is four with each having a spray target according to the location that is often sprayed by farmers when using conventional hand sprayers.

Figure 7. Flat-fan nozzle

Table 2. Specifications of the flat-fan nozzle

No.	Specification	Description
1	Material	Plastic
2	Length	6.5 cm
3	Diameter	1.94 x 0.48 mm
4	Thread	14 mm

The control system for this pesticide spraying machine uses a Cytron motor driver as the main component to control the two 12V DC motors that drive the track wheels. The Cytron motor driver was chosen for its ability to control the speed and direction of the motor's rotation through PWM (Pulse Width Modulation) signals. Additionally, the motor driver's current limit matches the motor specifications, allowing it to control motors with continuous currents up to 10 amps and a maximum current of 30 amps for 10 seconds. A relay is also used to control the pump, managing the on/off functionality of the sprayer pump. The relay allows the electrical flow to the pump to be controlled as needed, ensuring the pump operates only when required. Both the motor driver and relay are controlled wirelessly using a FlySky remote. This remote gives the operator control over the machine's direction and pump operation from a distance. In addition, the navigation system is equipped with an FPV (First-Person View) camera connected to the operator's smartphone. This camera provides a live feed from the machine's position, helping the operator monitor the machine's movement path via the smartphone. With the help of this live video feed, the operator can control the machine remotely more easily, reducing the risk of spraying errors and improving work efficiency.

Functional and Performance Testing

Functional testing of the machine was conducted on the frame, track wheels, pump, DC motor, FPV camera, transmitter-receiver, Cytron motor driver, relay, and nozzles. The success criteria for testing each component are displayed in Table 3.

Table 3. Success criteria for component testing

Component	Description
Frame	Capable of supporting and holding all components
Track Wheels	Capable of generating traction for optimal movement on the field
FPV Camera	Able to display a visualization of the path the machine will take on a smartphone within a radius of 50 meters
Fly Sky Remote Control	Capable of controlling the relay and Cytron motor driver from a radius of 50 meters
Cytron Motor Driver	Able to control the motor movement for straight and turning actions
Relay	Capable of controlling the power input to the pump

The performance of the driver system was tested by moving the machine across a 10-meter ridges field, with three replicates of the observation. The forward speed of the machine was calculated by measuring the time required to cover the 10-meter distance, then dividing the distance by the time taken. Slip was measured by comparing the actual travel distance of the machine over ten rotations of the drive wheel with its theoretical distance, which is calculated as $10\times\pi\times Dr$. Speed and slip measurements were taken two times for different tank load variations (100%, 75%, 50%, 25%, and 0%). The traction system's performance aimed for the machine to operate with slip under 30%.

Next, the spraying performance was tested by observing three main parameters: spray pressure, flow rate, and spray coverage. Spray pressure was measured using a pressure gauge to determine the pump pressure at the nozzle during spraying, which affects the amount of liquid sprayed. Measurements were taken with 1 to 4 nozzles over a period of 1 minute with two repetitions. The targeted pressure is 0.3-0.4 bar which minimizes the output of droplets below 100 µm. Droplet size below 100 µm allows for drift and overlapping (Balsari et al., 2017). The flow rate is measured by spraying liquid droplets at maximum pressure, and then the volume of liquid sprayed is measured using a graduated cylinder in liters per minute, following the formula $Q = v/t$, where Q is the flow rate, v is the volume of liquid, and t is the time. Measurements were taken for 1 to 4 nozzles within 1 minute with two repetitions. Spray coverage was measured to determine the area covered by the spray, using three bamboo sticks (120 cm high) with paper on each side according to the chili planting location in the bed. The spray results on the paper were then marked and measured to determine the range and distribution of the liquid from the machine.

Power consumption testing involved measuring the power used for traction and spraying separately with a multimeter. The traction power was measured by recording the current going to the driver motor. Current measurements were taken for different tank load levels (100%, 75%, 50%, 25%, and 0%) to determine how much power the machine required to move in the ridges field. The spraying power was measured to determine the current when the pump was activated. Current measurements were taken with 1 to 4 nozzles to assess the power needed for spraying based on the nozzle configuration.

RESULT AND DISCUSSION

Machine Manufacturing Process

The pesticide spraying machine in the field bed has been successfully fabricated using the design discussed earlier (Figure 8).

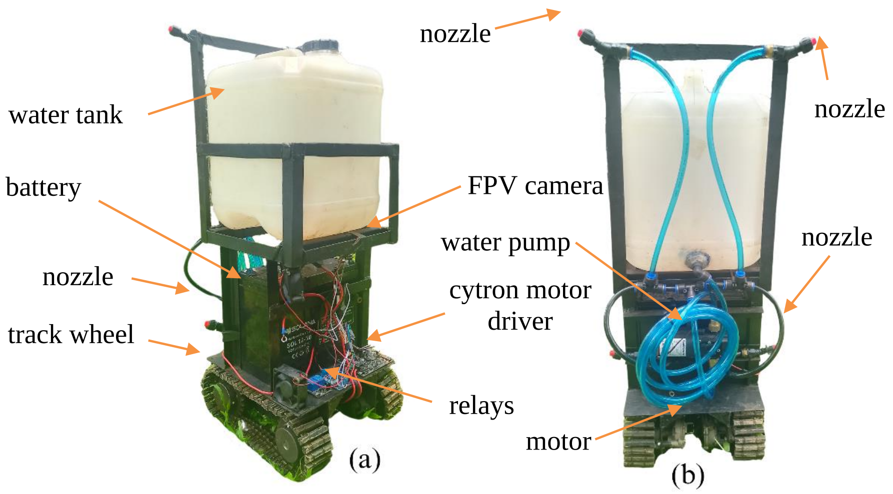

Figure 8. Machine spraying pesticides on chili plants isometric view (a), back view (b)

The manufacturing process of the pesticide spraying machine begins with the manufacture of the main frame which is designed to support all components of the tool such as the driver system and spray tank. The main frame is made of iron plate with a thickness of 3 mm and angle iron 2.5 mm x 2.5 mm. Furthermore, other components are installed, namely 12V DC motor, 12V pump, KFL 103 bearing, ass with a diameter of 13 mm, and track wheels. The track wheel itself is made of RS-40 gear with 24 teeth and is paired with an RS 40 chain with an additional ring on each connection that has been given a traction bearing in the form of a type A V-belt piece. After the main frame is installed, it continues with the installation of mechatronic components starting from batteries, cytron motor drivers, relays, and FPV cameras according to the place planned in the design.

Functional Test Results

Functional testing results show that all machine components operate properly and in accordance with design specifications. Tests were carried out on the frame, track wheels, pump, DC motor, FPV camera, flysky remote control, cytron motor driver, relay, and nozzle. The frame proved to be able to support all components, both the battery located in the centre and the jerry can be full of liquid located at the top. While the track wheels provide enough traction to move the machine in the field optimally both on land with clean conditions without weeds and on land with lots of weeds that allow more slip. This machine can be controlled remotely up to a radius of 200 meters, reducing direct pesticide exposure for farmers. The remote control system is supported by an FPV camera, which provides a clear visual display (Figure 9) of the machine's path within a 50-meter radius, ensuring effective navigation. This makes the machine highly effective for use in agricultural fields of up to 2,500 m² (50 × 50 meters). Another advantage of this design is the detachable water tank, which enables easy refilling on-site when the pesticide solution runs out. This capability addresses the challenges associated with the use of conventional backpack sprayers, which are still commonly used by farmers.

Figure 9. FPV camera image visualisation results on a smartphone

The FlySky remote can control the relay and cytron motor driver and able to regulate the movement of the motor both to go straight and manoeuvre U-turns from one furrow to another. The relay functions well in controlling the current into the pump which makes the pump turn on when switched on through a signal command from the flysky remote control. All components function according to the criteria set out in Table 3.

Performance Test Results

The results of the drive system performance test show that the machine can move at the targeted speed and slip rate. The pesticide sprayer machine is capable of operating on ridge fields and performing U-turn maneuvers (Figure 23). The average forward speed of the sprayer machine is 0.30 m/s, with an average slip rate of 8.32%. The minimum speed occurs when the water tank is full, at 0.27 m/s. As the water tank empties, the machine's forward speed increases. When the tank is empty, the machine reaches a speed of 0.34 m/s. These results indicate that the machine's average speed meets the predetermined target of 0.25 - 0.30 m/s. However, when the tank is empty, the machine moves faster than the targeted speed.

Figure 10. Machine in operation: (a) The sprayer machine performing a U-turn maneuver; (b) The sprayer machine during the spraying process

The slip generated when the machine moves, both in an empty and full tank condition, does not differ significantly. The minimum slip recorded was 6.49% when the machine operated with an empty tank. The maximum slip occurred when the tank was full, reaching 10.65%. The traction performance value produced by the engine remains low and meets the target, which the slip is below 30%. The measurement results for forward speed and slip can be seen in Table 4.

Table 4. Engine performance results

tank contents (%)	travelling time (s)	Number of Wheel Revolutions	Actual Speed (m/s)	Slip (%)
0	29,25	12,38	0,34	6,49
25	31,41	12,55	0,32	7,81
50	33,83	12,73	0,30	9,07
75	35,96	12,53	0,28	7,58
100	36,92	12,95	0,27	10,65

In the spray performance test, the spray pressure and liquid flow rate showed varying results depending on the number of nozzles used. The spray pressure, measured using a pressure gauge, was highest when using a single nozzle, with an average pressure of 2.06 bar. The spray pressure decreased as the number of nozzles increased. Tests with 2, 3, and 4 nozzles resulted in average pressures of 1.56, 0.98, and 0.35 bar, respectively. These results indicate that the use of a 4-nozzle design aligns with the effective pressure range for flat fan-type nozzles, which is between 0.30 and 0.40 bar. The maximum spray flow rate reached 1.35 L/min with a single nozzle. The flow rate decreased proportionally with the drop in pressure, with the variations of 2, 3, and 4 nozzles producing flow rates of 1.34, 1.09, and 0.87 L/min, respectively. The spray coverage achieved with the 4-nozzle configuration (2 nozzles on the right side and 2 on the left) successfully covered the entire target area, reaching the highest point at 120 cm from the top of the ridge. The spray coverage using flat fan nozzles extended up to 187 cm above the ridge. However, the use of 4 nozzles resulted in a high overlap value, indicating the need for further research to optimize spraying efficiency. The spraying performance values can be seen in Table 5.

Table 5. Spraying performance values

Number of nozzles	Flow rate (l/minute)	Pressure (bar)
1	1.35	2.06
2	1.34	1.56
3	1.09	0.98
4	0.87	0.35

The results of the power consumption test indicate that the power required by the machine varies depending on the tank load and nozzle configuration. In the traction power test, the current required to drive the motor increased as the tank load increased. When the tank was full, the recorded current reached 10.88 A, while at 50% tank capacity, the current dropped to 8.58 A, and in an empty tank condition, it required 7.85 A. The average power consumption for driving the motor was 9.10 A. During current measurements while turning the machine, a significant current spike of 15-19 A was observed. This surge was caused by additional traction resistance when both track wheels moved in opposite directions. The measured current values for the motor at a voltage of 12 volts are presented in Table 6.

Table 6. Current measurements at different tank contents

Tank contents (%)	Current (A)
0	7.85
25	8.9
50	8.58
75	9.25
100	10.88

The use of power in the spraying process requires a current that is not much different between the use of 1 to 4 nozzles. The power required with one nozzle is 2.15 A and the use of 4 nozzles requires 2.14 A, with the use of an average power current of 2.14 A. The results of these measurements show that the current in the pump is stable and not affected by the number of nozzle outputs. The pump current measurement results can be seen in Table 7.

Table 7. Pump current measurement results at different tank contents

Number of nozzles	Current (A)
1	2.15
2	2.12
3	2.15
4	2.14

Performance Test Results

The machine evaluation phase was conducted to identify potential shortcomings in the pesticide spraying process. The theoretical field capacity of the machine was determined to be 0.17 ha/hour based on the machine's average speed of 0.30 m/s. A comparison between this machine and conventional spraying methods revealed a significant difference. According to Sari and Prasetio (2021), the forward speed of conventional spraying using a backpack sprayer is 0.34 m/s, resulting in a theoretical field capacity of 0.10 ha/hour. This considerable difference is primarily because conventional spraying requires two passes on a single ridge to cover both the right and left sides of the plants, increasing the total travel distance. In contrast, the machine completes spraying in a single pass, as its nozzles simultaneously spray both sides. Theoretically, using this machine can reduce spraying time by 58 minutes compared to conventional spraying methods.

For pesticide application, the recommended dosage of Antracol 70 WP for a 0.25 ha field is 125-250 liters. In terms of spraying performance, the machine was able to spray 313 liters of pesticide solution in 90 minutes using four nozzles. In comparison, using only two nozzles resulted in 214 liters of sprayed liquid at the same forward speed. These results indicate that the output flow rate of two nozzles aligns more closely with the recommended application rate for Antracol 70 WP than using four nozzles.

A challenge was observed when the machine was operated continuously for more than 30 minutes, as the DC motors became noticeably hot. This condition increases the risk of overheating, which could affect the machine's subsequent performance. Therefore, further evaluation is needed regarding motor endurance for future machine designs

CONCLUSION

The pesticide sprayer machine test on a 2,500 m^2 chili cultivation field demonstrated promising results. The sprayer machine design was able to support the battery and water tank effectively while also allowing easy removal and reinstallation for refilling and maintenance. It performed well on both soil and asphalt surfaces, with the remote control operating effectively up to 200 meters. The FPV camera maintained a clear image up to 50 meters without obstacles. The average machine speed was 0.30 m/s, with an average slip of 8.32%. The speed increased when the tank was empty (0.34 m/s) and decreased when the tank was full (0.27 m/s), with slip ranging from 6.49% to 10.65%, depending on the tank condition.

The spraying test indicated that spray pressure and flow rate varied according to the number of nozzles used. The highest pressure was recorded with a single nozzle (2.56 bar) and decreased as the number of nozzles increased. The use of two nozzles provided an output flow rate that aligned well with the recommended pesticide dosage, delivering 214 liters over the test field within 90 minutes. The flat fan nozzle achieved a spray coverage height of up to 120 cm on the ridges. In the traction power test, the current required to drive the machine increased as the tank load increased. When the tank was full, the current was recorded at 10.88 A, decreasing to 8.58 A at 50% capacity and 7.85 A when empty. The average motor power consumption was 9.10 A, with current spikes ranging from 15 to 19 A when the machine turned due to the traction resistance caused by the opposing movement of the track wheels. Power consumption during spraying remained stable regardless of the number of nozzles used. The power requirement for a single nozzle was recorded at 2.15 A, while four nozzles required only a slightly different current of 2.14 A, with an average usage of 2.14 A.

The pesticide sprayer machine demonstrated efficient performance, reducing spraying time to 58 minutes compared to conventional spraying methods while maintaining reliable operation across various land conditions. The use of remote control technology allows farmers to operate the machine from a safe distance, effectively minimizing direct exposure to pesticides that could negatively impact their health. Additionally, this machine is adaptable for use on other horticultural crops with similar characteristics, such as melons, tomatoes, and other row-planted crops, making it a versatile solution for precision pesticide application in various agricultural settings.

For future research, it is recommended to conduct further studies on cost analysis to evaluate the economic feasibility of the machine. Additionally, more in-depth research on spraying effectiveness, including factors such as wind speed, humidity, and their impact on pesticide deposition, should be explored. Further analysis of the machine's maneuverability on sloped terrain and an ergonomics study on its usability for farmers would also provide valuable insights for improving the machine's design and operational efficiency.

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CONFLICT OF INTEREST

All authors declare that there is no conflict of interest.

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